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TECHNICAL REPORT NO. 1-770

NUCLEAR WEAPONS EFFECTS ON DAMS AND OTHER SUBMERGED AND SEMISUBMERGED HARD TARGETS

Report 1

LITERATURE SURVEY AND PROPOSED RESEARCH TO STUDY DAMAGE FROM CONTACT BURST

by

L. K. Davis

A. D. Rooke, Jr.

April 1967

Sponsored by

Defense Atomic Support Agency

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

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PREFACE

This study was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Defense Atomic Support Agency (DASA) and was performed as a part of Nuclear Weapons Effects Research Subtask 14.099. The work was accomplished during the period September 1965 through January 1966 under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief of the Nuclear Weapons Effects Division, and Mr. J. N. Strange, Chief of the Engineering Research Branch. This report was prepared by Messrs. L. K. Davis and A. D. Rooke, Jr.

Col. John R. Oswalt, Jr., CE, was Director of the WES and Mr. J. B. Tiffany was Technical Director during the preparation and publication of this report.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	25.4	millimeters
feet	30.48	centimeters
pounds	0.45359237	kilograms
kilotons	907.185	metric tons

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In order to effectively utilize low-yield nuclear weapons to achieve specific results, it is necessary to know in detail the capabilities of these weapons. Although the general results desired from low-yield nuclear weapons employed on hard targets are similar to those desired from conventional bombs or demolition munitions, the occurrence of secondary effects associated with nuclear weapons may often impose limitations on the weapon yield or emplacement. It may be desirable to limit the extent of damage inflicted so that the installation can be made operative by friendly forces at a later time, in keeping with the maxim that destruction should never be greater than necessary to accomplish a given mission. Finally, weapon assemblies which offer sufficient operational flexibility to permit their use in demolition tasks (considering weapon size, weight, firing procedure, etc.) are often limited to small yields. Thus, low-yield weapons often are the best suited of the nuclear arsenal for specific destruction of point targets.

Since the potential of nuclear weapons for demolition or tactical destruction was first realized, considerable effort has been made to develop methods for analyzing and predicting the capabilities

of low- and very low-yield weapons and to establish operational procedures for missions involving their employment. Numerous manuals and technical reports have been published in connection with the employment of these weapons, and these generally fall into two categories: (1) Department of Defense manuals dealing with procedures for employment of low-yield weapons in combat operations, including atomic demolition munitions (ADM's), which encompass several technical reports designed to aid military personnel in the selection of the proper weapons and emplacement method, and (2) technical investigations and analyses of low-yield nuclear weapon capabilities and effects.

Damage from nuclear weapons may be inflicted in a number of ways: by airblast, ground shock, cratering action, radiation contamination, etc., depending on the type of target and the damage mechanism(s) to which it is vulnerable. However, cratering action is by far the most significant damage mechanism involved in the destruction of hard structures which, because of their massive construction, are relatively invulnerable to less direct weapons effects.

There are two general types of hard structures. Those which have been intentionally hardened, such as underground command centers, missile silos, and similar installations, may be classified as strategic targets, and as such are not ordinarily considered targets

of tactical demolition missions. Structures which are naturally hard, however, such as concrete dams, large bridges, or highway and railroad tunnels, may be targets of tactical (as well as strategic) operations. The problem being considered in this study is the destruction or damage of targets in this latter category, and due to the broad scope of this category, it will be further restricted here to targets which are submerged or semisubmerged.

1.2 OBJECTIVE

The objectives of this report are to examine the current state of knowledge concerning the effects of low-yield nuclear weapons employed on submerged and semisubmerged hard targets, to determine in what respects this knowledge needs to be expanded, and to propose a program of investigation and experimentation by which such expansion can be accomplished.

1.3 SCOPE

Twenty-five technical publications are reviewed in Chapter 2 of this report. The first two groups of references represent the state-of-the-art of the employment (References 1 through 6) and effects (References 7 through 10), respectively, of low-yield nuclear weapons on submerged and semisubmerged hard targets with primary emphasis on demolition techniques. References in the third group (References 11 through 25), which is concerned with related phenomena, were included

because of their applicability to the formulation of a program to further develop the state-of-the-art by small-scale testing. Also included in the list of references are References 26 through 38 which, although not reviewed in Chapter 2, are of general interest in connection with this subject. In Chapters 3 and 4 the information contained in the references is discussed, areas in which sufficient knowledge is lacking are defined, and a proposed research program is developed.

CHAPTER 2

LITERATURE SURVEY

In the following sections, twenty-five publications are briefly reviewed as a collective summary of the state of knowledge concerning the employment of low-yield nuclear weapons in attacking submerged and semisubmerged hard targets. The references selected represent the best information currently available to the authors and deal directly with or apply to some facet of the problem being studied. In general, these references are grouped into three broad categories:

1. Manuals concerned with the employment of low-yield nuclear weapons, including (1) descriptions of available low-yield nuclear weapons and their operational characteristics, (2) standing operating procedures for employment of low-yield nuclear weapons in tactical warfare, and (3) general effects of low-yield nuclear weapon employment.

2. Technical analyses of low-yield nuclear weapon effects applicable to submerged or semisubmerged hard targets.

3. Investigations of related phenomena.

The reports reviewed were examined in varying degrees of detail according to their actual or potential bearing on the effects of low-yield nuclear weapons on submerged and semisubmerged hard targets.

2.1 MANUALS CONCERNED WITH THE EMPLOYMENT OF LOW-YIELD NUCLEAR WEAPONS

2.1.1 "Employment of Atomic Demolition Munitions (U)," Reference 1. This manual is designed as a guide for tactical commanders and staff officers in the operational and logistical aspects of ADM employment. The principal types of ADM targets are described, with several examples of typical target analysis problems for ADM employment. In addition, this manual contains a brief discussion of cratering phenomena and damage criteria for a hypothetical family of ADM's. The importance of the true crater and rupture zone is recognized, and equations are given which permit an approximation of the true crater and rupture zone dimensions, based on weapon yield, depth of burst, or apparent crater dimensions. Cratering curves (scaled apparent dimensions versus scaled depth of burst) are presented for three media categories: dry soil and soft rock, marine muck, and residual clay. The ADM yield required for employment on various targets is selected by determining, from auxiliary curves, the yield which will result in a crater dimension that exceeds one or more critical dimensions of the target structure. For example, to destroy a bridge by weapon emplacement on the face of the bridge pier, a yield is selected which will produce a true crater diameter plus rupture zone in hard rock which is equal to the width of the pier.

2.1.2 "Nuclear Weapons Employment (U)," Reference 2. This is an Army field manual which contains tabulated data on the characteristics of various nuclear weapons and delivery systems. The manual is primarily devoted to probable damage radii for different target types according to weapon yield, delivery system, target range, etc., and is intended for staff use in nuclear weapons employment planning.

2.1.3 "Capabilities of Atomic Weapons (U)," Reference 3. This manual provides the military services with an overall discussion of and with prediction techniques for the assignment of nuclear explosion phenomena and of their effects (in terms of damage) on targets of military interest. Procedures, graphs, and charts are presented in this reference which make possible the prediction of the various phenomena and effects of nuclear detonations that take place above, at, or below an air-ground or air-water interface.

The 1957 edition is based on weapons effects data accumulated prior to the publication date, and in some cases the margin of error for predicting crater size is much greater than the margins stated in the manual (based upon comparison with the newer manual). The 1964 edition presents prediction curves based on more extensive and more recent data, but this edition has been in general circulation for only a short time, and the updated prediction curves have not been incorporated in most of the recent technical reports dealing

with the effects of low-yield nuclear weapons.

2.1.4 "Techniques of Employment of Atomic Demolition Munitions (U)," Reference 4. The first volume of the report provides a technical reference on ADM employment techniques against a number of different target types, such as earth fills, airfields, ports, dams, locks, bridges, tunnels, underground structures, and industrial plants. The effects on the size of the crater and the shape of its surface versus degree of containment of detonation, inhomogeneities in the cratered medium, and other factors are discussed, primarily from a qualitative viewpoint. Most of the weapons effects data for various nuclear yields was taken from the 1957 edition of Reference 3.

The conclusions reached in this study are restricted to the specification of a small yield and emplacement positions which insure destruction of each particular type of target, but no conclusions are reached as to the type or extent of damage that can be expected, other than sufficient destruction of the target.

The second volume of the report is an addendum which describes specific examples of typical targets for ADM missions and theoretical demolition procedures for employing ADM's against these targets. The 35 targets analyzed include bridges, causeways, airports, seaports, dams, tunnels, utility structures, and utility installations.

2.1.5 "Guide for the Use of Nuclear Explosives in Bridge Demolitions," "Guide for the Use of Nuclear Explosives in Dam and Waterway Demolitions," and "Guide for the Use of Nuclear Explosives in Tunnel Demolitions," Reference 5. The material contained in these publications was prepared for inclusion in a Defense Atomic Support Agency manual on the use of nuclear explosives (NE). These reports consider the basic types of bridges, dams, canals, and tunnels and the methods by which they can be destroyed by nuclear demolition. Specifically, they examine the positions at which the charge could be placed and the extent of destruction that would result therefrom. The nuclear yield required is determined by relating the target material to a medium which must be "cratered" to a certain depth or width sufficient to cause failure of the structure. For example, to destroy a bridge pier, these reports state that a yield must be selected which would crater a similar medium to a depth (or width) equal to the pier thickness (or width). For charges placed under an earth cover or under water, an "effective" depth of burial is calculated for an underground burst in rock to obtain the theoretical crater dimensions, the effective depth being calculated from the actual depth of burst changed to reflect the densities of the earth or water relative to that of rock. The estimates of yields required to produce the degree of cratering or damage required are generally based on the cratering data of the 1957 edition of Reference 3.

2.1.6 "Military Engineering with Nuclear Explosives," Reference 6. The purpose of this manual is to provide basic engineering data, technical guidance, and employment criteria for planning and executing military engineering operations involving the use of nuclear cratering explosions. The manual discusses the characteristics of nuclear explosives and their cratering capabilities (including an explanation of the mechanics of cratering), the hazardous side effects associated with nuclear cratering explosions (airblast, fallout, etc.), and emplacement techniques for the employment of ADM's against engineering structures. The section of the manual dealing with ADM employment contains illustrative examples of the procedure for selecting an ADM yield and emplacement location for use against typical engineering structures such as dams, tunnels, airfields, and bridges. The procedures recommended are similar to those set forth in Reference 5, except that the primary measure of destruction by cratering in this manual is considered to be the depth or radius of the true crater, rather than that of the apparent crater. The nuclear weapon yields and corresponding crater dimensions are based mostly on data from large-scale HE and NE tests at the Nevada Test Site.

2.2 TECHNICAL ANALYSES OF LOW-YIELD NUCLEAR WEAPONS EFFECTS

2.2.1 "Estimated Weapons Effects of Fractional Kt Nuclear Weapons (U)," Reference 7. The objective of this study was to

estimate the effects of fractional-kiloton[1] yield munitions and the military significance of these effects. Predictions are made for the apparent and true crater dimensions for various yields at different heights or depths of burst in several media. These predictions are based on extrapolations of the curves for higher-yield nuclear devices as given in the 1957 edition of Reference 3. In addition, predictions are made for other weapons effects such as airblast, thermal and radiation effects, etc., in order to compare the increase in destructive efficiency with the decrease in side effects due to more advantageous placements of smaller yield weapons. The tactical advantages of using weapons that have very small yields for both demolition and military construction are discussed.

2.2.2 "Recommendations for Employment of Atomic Demolitions (U)," Reference 8. This report analyzes the employment of ADM's on 10 different target types and presents recommendations for their employment. A technique is developed for scaling high-explosive (HE) craters to those expected from nuclear explosions. The technique is based on the relative energy-density values for HE and NE and on an NE-HE efficiency range for use with different media and depths of burst. The technique, in turn, forms the basis for the yield requirements for an ADM target, since it is assumed that cratering is the

[1] A table of factors for converting British units of measurements to metric units is presented on page 8.

primary effect utilized in the ADM employment. Much of the material covered in this report is presented in a more advanced form in Reference 11.

2.2.3 "Structural Damage with Atomic Demolition Munitions," Reference 9. This report is concerned with the effects of ADM employment against structures which may become targets of demolition during military retrograde operations. The discussion is oriented toward protective construction, i.e. structures intentionally hardened for defensive purposes.

The first portion of the report contains a literature review of existing publications pertaining to structural damage by conventional and atomic demolition munitions. In the main body of the report, two methods are presented for predicting damage experienced by buried structures subjected to deliberately placed ADM's. Damage is defined in terms of structural failure only. One method is concerned with structures located within the crater zones, and is applied to tunnels and protective shelter type structures. This method involves relatively simple formulae for computing crater or cavity sizes and rock penetration distances (radii of rock breakage) for contained or partially contained detonations. It is essentially an empirical approach, based on the comparative volumes for surface and canouflet shots in rock. The second method is concerned with structures located away from the crater zones, where the primary damage mechanism is ground

shock. This method requires considerable input data, such as structural and material properties, yield resistance functions, and free-field pressure data. It is applied to reinforced concrete and steel arches and reinforced concrete box type structures. Failure criteria are based on the effects of peak pressure applied to those structures that are adequately represented by a "single degree of freedom" analytical solution.

2.2.4 "Nuclear Weapons Effects on Dams (U)," Reference 10. This report summarizes the procedures, to the extent that currently available data will permit their formulation, for estimating the damaging effects of nuclear weapons on various types of dams. In the process of developing damage prediction methods for the various types of dams considered, it became obvious that there exist a number of areas wherein little or no data are available to aid in providing quantitative prediction techniques. In still other instances, the study revealed that the statistical confidence levels for predicting explosion effects and structural response were very unsatisfactory, and thus more definitive study is required to improve prediction methods.

The study also provides worldwide statistics on dam shapes, heights, etc., and proposes techniques for inferring detailed descriptions of the dam geometry from only one or two linear measurements.

2.3 INVESTIGATIONS OF RELATED PHENOMENA

2.3.1 "Close-in Effects of Nuclear Explosions," Reference 11. The purpose of this report was to investigate by analytical means

the close-in effects of nuclear and conventional explosions, particularly in regard to the formation of craters and the calculation of transient subsurface stresses in the close-in region. The latter portion of the objective was accomplished by an examination of the deviative effects which characterize or influence high-intensity stress-wave propagations, with an analysis of surface spall phenomena from deeply buried detonations.

The major part of this report is concerned with the development of a correlation between the early time histories of HE and NE explosions. The correlations are based on (1) the energy-density balance and energy distribution in the hydrodynamic region at early times after detonation, and (2) the transmission of shock energy in the intermediate and elastic regions as a function of the Hugoniot characteristics of the medium. Hugoniot curves are presented for several different media, and HE-NE efficiency factors are derived for surface, shallow, and deeply buried explosions in these media.

2.3.2 "Effects of Atomic Demolition Munitions (U)," Reference 12. This report is essentially an extension of the material covered in Reference 11 to include an application of NE-HE equivalence factors to the effects of specific types of ADM's. The influence of material and weapon properties on the NE-HE equivalence factors is examined in detail, with particular regard to the change

in the amount of nonrecoverable heat loss as a function of surface and near-surface burst geometries, and as a function of the ratios of the weapon yield to weapon volume and mass. Curves are presented for predicting crater sizes as a function of burst depth in various media from specific types of ADM's.

2.3.3 "Calculations and Predictions of Shock Wave Phenomena and Cratering Effects Produced by Point Explosions with Regard to Underwater Explosions (U)," Reference 13. This report is a theoretical investigation of the shock wave phenomenology occurring when a nuclear weapon is detonated at the interface between two semi-infinite media, specifically considering a soil-water interface. The investigation basically consists of two parts; the first deals with the energy partition of the explosive energy at the interface within the close-in region, and the second is a prediction method for craters formed underwater as a result of such explosions.

The analysis of the shock-propagation characteristics in the hydrodynamic region is essentially based on the wave-form distributions and Rankine-Hugoniot relations originally developed by Porzel. These equations are further developed by considering the balance of the kinetic, hydrodynamic, and waste-heat energies across the shock front. By assuming that the shock-front pressures in the two media are equal at all times and that the distance from the point of burst to the shock front along the interface is equal in

each medium at any time, the partition of the total available energy can be found and the conditions within the shock front at any time can be described for each medium.

A method for estimating the size of craters produced in a homogeneous bottom medium is developed by applying the conservation of mass law to the shocked volume of soil in the interface situation. From this method, curves are presented for predicted crater radii and lip heights formed by a range of nuclear yields (1 kt and above) in three different bottom materials (clay, coral, and mud). These dimensions are given as the maximums to be expected, since it is assumed in the calculations that the water is deep enough not to inhibit the crater formation by a premature release of energy to the air. In this light, a second curve is presented for water depths theoretically required to assure completion of the energy-coupling process into crater formation prior to venting for a range of explosive yields.

<u>2.3.4 "Underwater Craters Formed by Explosions on the Sea Floor," Reference 14</u>. The purpose of this investigation was to determine the effects of charge weight, charge shape, water depth, charge composition, and type of bottom material on the size and shape of craters formed by explosive charges on the sea floor.

Of the sixty-three charges fired during the experimental phase, the majority were trinitrotoluene (TNT); the remainder were various types of military explosives in use during World War II. No

significant deviations were observed in the crater size or shape due to the differences in explosive types. The charge weights ranged from 3.75 to 290 pounds and were detonated in water depths varying from 0 to 20 feet. The three media cratered were sand, mud, and a rocky bottom consisting mostly of stones about 4 inches in diameter. The apparent depth, diameter, and volume of each crater were measured and scaled by cube-root scaling (cube root of the charge weight).

The results of these tests indicated that, within the accuracy of the crater measurements, the dimensions of the craters followed the cube-root scaling law. It was also found that the crater volumes increased significantly (up to five times) with an increase in scaled water depth from 0 to 0.67 $ft/lb^{1/3}$, with only slight increases thereafter up to a depth of 4.0 $ft/lb^{1/3}$. The volumes of the craters produced on the mud bottoms averaged about two and a half times the volumes of the sand-bottom craters, whereas the volumes of the craters on the rocky bottoms were roughly half those produced on the sand bottoms.

2.3.5 "Summary Report of the Experiment of Underwater Explosion Under Controlled Conditions (U)," Reference 15. This report contains a summary of the apparent crater dimensions from a series of experiments on the effects of underwater explosions under controlled conditions. The charges fired in these tests were 1-pound

spheres of Composition 3 (C-3). The variables in the tests were water depth (0.1 to 4.0 feet), depth of burst (0.5 feet above water to bottom), and type of bottom material (mud, sand, and concrete). In this report, however, only the results of the tests on the sand bottom are given. Several graphs are presented showing the variations in the crater dimensions as a function of the charge depth for these and previous tests, and the crater profiles are plotted for 42 shots over the sand bottom.

2.3.6 "Effects of Explosions in Shallow Water," Reference 16. This study was initiated to determine, by means of small-scale charges, the results of a 20-kt explosion in water depths of 30, 60, 100, and 200 feet with respect to cratering, water-surface waves, airblast, and water and ground shock. Charge weights varying from 1/2 to 2,050 pounds were fired in a test basin and at various field test sites over three different types of bottom materials--sand, loess, and clay. Measurements were made of the apparent craters formed and their dimensions related to variations in the charge yield, water depth, depth of burst, and type of bottom material. Curves of the test results were plotted to confirm charge-yield scaling factors for the crater dimensions. Finally, the test results were extrapolated to predict the results of a theoretical 20-kt nuclear explosion in a shallow-water harbor.

2.3.7 "Underwater Cratering (U)," Reference 17. This report

discusses the underwater formation of apparent craters by large-yield chemical and nuclear explosions. Essentially, the report consists of two parts: a discussion of the current theories pertaining to the formation of underwater craters, and an examination of the factors that influence underwater crater formation.

In the treatment of the cratering theory and prediction methods, the analytical procedures developed by several authorities, such as Porzel, Chaszeyka, Anderson, and Brode, are briefly outlined and discussed. In addition, the variables involved in underwater crater formations are examined. These variables are defined by the shot geometry and the properties of the fluid, the bottom material, the explosive, and the environment. Crater-scaling factors are developed by dimensional analysis to ascertain the influence of these variables on underwater crater prediction techniques. The scaling factors, in turn, are then compared with experimental results from actual underwater cratering tests, primarily those involving nuclear explosives. To illustrate the effects of the major test variables on the final crater dimensions, several curves are derived on the basis of actual test data and the scaling trends developed.

The second portion of this report deals with other phenomena which may exist or occur during an underwater cratering event and which may alter the cratering process or the final crater

configuration. In particular, the effects of washback in the crater, layered bottom media, and crater slope stabilities are discussed.

2.3.8 "The Effects of Explosions on Gravity-Type Dams," Reference 18. The objectives of this investigation were to determine the magnitudes and distributions of water-shock pressure and impulse at various distances from an underwater explosion in various depths of relatively shallow water, and to develop procedures for predicting the response of concrete gravity-type dams to such loadings. The actual test program consisted of two parts. In the first, a series of 8- and 32-pound TNT charges were detonated in shallow water to obtain measurements of pressure and impulse at various distances from the charge, both in the free field of the water and on the face of a submerged vertical wall. In the second part of the program, a 6-foot-high test dam was constructed and tested with 830-pound TNT charges to verify the predicted ranges at which (1) cracking of the structure would occur, and (2) major damage would result.

2.3.9 "Modeling and Analysis Techniques for Evaluating the Effects of Dynamic Loading on Gravity Dams (U)," Reference 19. The objective of this report was to develop modeling and analysis techniques for evaluating the effects of a dynamic loading produced by water shock on gravity dams. The first approach was a theoretical analysis of the stress-strain problem created by the dynamic loading condition applied at the submerged face of the dam. The stress-wave

analysis was performed by considering a two-dimensional section of the dam as a lattice of finite lumped masses interconnected by massless springs. A computer program was written to calculate displacements from plane (two-dimensional) strain of the lattice units subjected to a plane stress wave which was time-dependent. Peak stresses were calculated at various positions in the dam cross section.

The second approach used was a model test of a cross-sectional "slice" of the dam. To simulate a "scaled gravity" load on the model, pretensioned cables were attached at twenty-three points in the cross section. The dam was instrumented to obtain data on water-shock pressure, strain and deflection in the dam, and the resulting cracking pattern in the cross section.

2.3.10 "Hasty Demolition of Concrete Structures," Reference 20. The purpose of this test program was to determine the minimum explosive necessary to breach reinforced concrete piers 1 to 8 feet thick. A subordinate objective was to enhance understanding of the principles surrounding the destructive effects of explosives on a target.

The test piers ranged in thickness from 4 inches to 7 feet. Charge weights varied from 25 grams to 250 pounds of C-4. The influence of the following factors on breaching ability was studied: (1) ratio of charge thickness to contact area, (2) height of charge above pier base, (3) charge-initiation point, and (4) tamping of

the charge. Measurements were made of the craters both on the charge side and on the opposite or spall side of each pier, and cracking patterns in the concrete were noted.

It was concluded that the methods of charge initiation utilized in the experiment had no effect on breaching ability, while the effects of charge tamping (for wall thicknesses greater than 1 foot) were inconclusive. Placement of the explosive at least one thickness of the pier above the base of the pier was found to be more effective than placement at the base. Most significant was the effect of the ratio of the charge thickness to the contact area between the charge and the pier. An optimum ratio was found to exist for breaching ability, the critical ratio decreasing from 1:40 for the 1-foot-thick piers to about 1:435 (estimated) for 8-foot-thick piers. The minimum charge weights required to breach the piers varied from 2.5 pounds of C-4 for a 1-foot-thick pier to 480 pounds (estimated) for an 8-foot-thick pier.

2.3.11 "Demolition of AASHO Standard Type III Prestressed Concrete Bridge Beams with High Explosives (Phase II)," Reference 21. The objective of this report was to evaluate explosive techniques for demolition of large, pretensioned, prestressed concrete bridge beams. Test charges of TNT, plastic, and flexible explosives in weights of 2.75 to 75 pounds were detonated on the tops, sides, and bottoms of simple beam spans to determine the optimum

weight, shape, and placement of the various explosives for efficient demolition. It was concluded that the dual side breaching technique was by far the most efficient. Effective demolition of simply supported spans of the pretensioned, prestressed concrete I-beams required only the breaching of the concrete away from the stressing steel so the severed beams could fall freely.

<u>2.3.12 "Demolition of Concrete Locks on the Ohio River (Research Phase)," Reference 22</u>. This report covers tests of demolition techniques used against massive, nonreinforced concrete walls. Charges were detonated on the concrete wall above the water level, and the results were compared with those of charges detonated on the wall below the water level. An opposed-charge technique was also tested.

The test wall was a 600-foot-long lock wall on the Ohio River, scheduled for demolition. Seventeen charges were fired, ranging in weight from 30 to 80 pounds of C-4. Ten of the tests involved 40-pound charges fired at depths of 2.5 to 7 feet below the water surface against a 5-foot-thick wall. Some of the charges were placed on the deepwater side of the wall and others on the shore side, where a silt bottom lay from 2 to 10 feet below the water surface. In addition, two 50-pound charges were fired slightly above the water level on the wall, and two opposed charges (20 pounds on each side of the wall) were fired, one above the water level and one below.

After each shot, the depth of the breach (from the top of the wall), if any, and the crater dimensions on each side of the wall were measured. Photographs were also made.

It was concluded that: (1) 40 pounds of explosives was required to breach the wall if the charge was placed at a minimum depth of 5 feet underwater, and 60 pounds was required if the charge was placed above the waterline; and (2) the opposed-charge technique was not effective for long concrete structures.

2.3.13 "Research Studies on Tunnel Demolition (U)," Reference 23. The purpose of these studies was to examine the factors which are important in producing various degrees of tunnel damage (i.e. closure, spalling, etc.), and to investigate the effects of these factors in small-scale tunnels. The two volumes of this report represent the two phases of the program; Phase I was an investigation of hasty demolition techniques, and Phase II was a study involving deliberate demolition of tunnels.

For Phase I, a number of one-tenth- to one-fifth-scale tunnels were constructed of unreinforced concrete. C-3 demolition charges were placed near the tunnel portal and in the center of the tunnel floor for each test. In some cases, successive charges were fired until the tunnels were completely destroyed. The tunnel walls varied from 2 to 6 inches in thickness, and were backed by sand in some tests, while exposed in others. Strain gages on the liners

and airblast gages in the tunnel openings were used in several of the tests.

For Phase II of the program, four one-tenth-scale tunnels were drilled in the face of a dolomite formation. The demolition charges for these tunnels were placed in small-diameter holes drilled parallel to the tunnels. In each case, small charges were simultaneously fired first in the hole to the right side of the tunnel, then in the hole on the left side, and finally in the hole above the tunnel until destruction of the tunnel was complete. After each firing, the tunnels were examined to assess the damage and determine if a succeeding shot was required. The charge weights ranged from 0.75 to 8 pounds and the scaled depth-of-burst ratios (charge distance from tunnel axis divided by tunnel height) ranged from 1.5 to 1.83.

Both volumes of the report correlate the test results obtained with previous model or full-scale tests of similar nature conducted by other agencies. This analysis includes a review of the laws of similitude and a discussion of the significance of cratering test results in various types of rock with the results of tunnel demolition tests.

2.3.14 "Effects of a Soil-Rock Interface on Cratering," Reference 24. This report is concerned with the effects of a subsurface soil-rock interface on cratering and ground-shock phenomena. A

series of 27-, 54-, and 256-pound charges (TNT, C-4, and dynamite) were fired in a sand medium with an underlying massive concrete base slab simulating a natural bedrock formation. The apparent and true craters in the sand and concrete were measured and analyzed as a function of the charge weight, depth of burst, and depth of overburden. The sand-column technique[2] was employed to investigate the influence of the soil-rock interface on the cratering process.

2.3.15 "On Fractures Caused by Explosions and Impacts," Reference 25. This is essentially a textbook on the principles of fractures caused by impulsive loads. In addition to the mathematics and physics of spalling phenomena, this text discusses in detail the effects of interfaces, body shapes, and strain- and stress-wave shapes on spalling and fracturing of hard materials.

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[2] Vertical columns of a dyed sand-lime-water mixture embedded in the cratered medium prior to the shot and excavated and surveyed after the shot.

CHAPTER 3

DISCUSSION

3.1 EFFECTS OF LOW-YIELD NUCLEAR WEAPONS ON SUBMERGED AND SEMI-SUBMERGED HARD TARGETS

From a survey of the previously listed references, it may be generally concluded that, for the destruction of a hard target by a nuclear weapon, the primary damage mechanism is that of cratering. Although other effects may, in certain instances, be important (e.g. damage inflicted by airblast or by strong ground motions on motion-sensitive targets), they represent specific cases which will not be considered in this report. It appears a safe assumption that an investigation of the effects of low-yield nuclear weapons on hard targets may be regarded as essentially an investigation of cratering that results from nuclear explosions in close proximity to massive structures.

3.1.1 Selection of Significant Parameters. Assuming that cratering is the principal damage mechanism, the first, obvious step in this investigation is to determine what specific information is required in order to predict the effects of low-yield nuclear weapon detonations on submerged or semisubmerged hard targets. If an attempt is made to estimate, within reasonably close tolerances, the maximum and minimum damage to be expected from a nuclear cratering event or to define the minimum damage that will cause a

failure in a hardened structure, then an appropriate crater parameter must be selected. In many previous reports, the apparent crater dimensions (see crater notation in Figure 3.1) have been somewhat arbitrarily selected as the governing factor in this respect. Only recently has the technical literature on this subject indicated recognition of the fact that the true crater or rupture zone dimensions may more realistically reflect the potential of small-yield weapons to achieve satisfactory destruction of hard targets (Reference 1). In the following discussion, the significance of the various measures of cratering effectiveness as related to the attainment of the most efficient method of destroying typical hard target structures, i.e. the minimum energy expenditure required to achieve satisfactory destruction, is examined.

1. Bridges. The most probable locations for emplacement of ADM's in bridge demolitions are on the roadway, against a supporting pier, or against an abutment. If the roadway option is used, it is obvious that although the true crater depth may extend below the thickness of the bridge deck, the span will not necessarily collapse since the outer supporting beams may be beyond the true crater radius. This occurrence seems quite likely, as the width-to-thickness ratio for most bridge spans is much greater than the width-to-depth ratio for an average true crater in rock. Therefore, the true crater radius would be the controlling dimension. If

the weapon is placed against a bridge pier or abutment, however, the true crater depth would be more important, since the width-to-thickness ratio for a solid pier or abutment would usually be less than the width-to-depth ratio for a true crater, and since destruction of a sizable portion of the cross-sectional area of the pier or abutment would be expected to result in failure. If the static structural forces on a pier or abutment are considered, the depth of the rupture or fracture zone would cause failure if it is equal to or greater than the pier or abutment thickness (Figure 3.2).

2. Dams. For detonation of a nuclear weapon at the top of a concrete arch or gravity dam, the true crater depth is obviously the critical dimension, since the depth of the breach must fall below the water level of the reservoir behind the dam to insure effective destruction. For detonation within or at the base of the dam, the depth of the rupture zone becomes more significant, since the ruptured and broken part of the dam would offer little or no resistance to the water pressure against it (Figure 3.3).

3. Tunnels. In the case of tunnels underwater or beneath a water table, the radius of the severe rupture zone created by a contained or partially contained explosion within the tunnel would probably be the most applicable measure of destruction, with the resulting accumulation of debris and water causing the tunnel's loss. On the other hand, if the weapon is detonated underwater above the

tunnel, both the true crater depth and the depth of the rupture zone are important. If the true crater extends to the depth of the tunnel, then complete destruction of a portion of the tunnel is assured. If the rupture zone alone extends to the tunnel depth, then the tunnel would at least be unusable due to flooding (Figure 3.4). If neither the true crater nor the rupture zone penetrates the tunnel, severe damage may still be inflicted through spalling of the tunnel roof and walls and from misalignment of the tunnel liner.

It appears that the true crater dimensions and the extent of the rupture zone are both extremely important in predicting the effects of low-yield nuclear weapons on submerged or semisubmerged hard structures. The extent of rupturing and fracturing of a hard medium by cratering explosions has been relatively neglected in investigations or predictions of low-yield nuclear weapon effects, and this phenomenon becomes particularly significant for underwater or below-bottom targets.

3.1.2 Prediction of Explosion Effects. Once the important cratering parameters have been established, the next question is how the magnitudes of these parameters can be predicted for nuclear explosions. For completely contained explosions, considerable data exist, and it is relatively easy to satisfactorily predict the cavity radius and even the radius of rupture for contained events in a variety of media (Reference 26).

Of the references reviewed in the literature study, the analytical theory for predicting crater dimensions from nuclear explosions suggested in Reference 11 is noteworthy. By balancing equations for the hydrodynamic and kinetic energies contained within the shock-front volume for nuclear and HE explosions, an NE-HE equivalent was determined for cratering yields for several media whose Hugoniot equations are known. On the basis of these equivalents, it is then possible, according to Reference 8, to obtain crater dimensions for theoretical nuclear explosions by the use of existing crater dimension curves for HE explosions. NE-HE equivalents were derived for surface bursts and for cratering bursts at optimum depths of burial.

Some investigations have been made of means of predicting the extent of rupturing and fracturing of hard media by contained or partially contained explosions (Reference 27), but relatively little work has been done in this respect for surface or near-surface cratering events, either NE or HE. The Waterways Experiment Station has done a limited amount of study of rock breakage and fracturing, including one experiment involving a large HE surface detonation (Reference 28). Some measurements were made of both true craters and extent of fracturing from HE explosions in a rock medium during the Engineering Research Associates, Inc., tests (Reference 29). In summary, some scattered data do exist on rock breakage and fracturing

by NE and HE explosions, but there is a definite lack of correlation between damage capabilities by rock breakage from explosions and the actual employment of low-yield weapons on practical targets.

3.1.3 Evaluation of Explosion Environment. The third important problem that arises in analyzing low-yield nuclear weapons effects is to determine in what manner, if any, the shot geometry and/or field conditions will affect the crater dimensions, which in turn govern the yield requirements. For example, how will the true crater depth vary for a contact explosion atop a thin, trapezoidal (in section) structure, such as a gravity dam, as opposed to a contact explosion on the surface of an infinite medium? Almost all crater prediction theory is based on the latter case, but the vertical sides (boundaries) of a typical dam would act as sources of shock reflection which, in turn, would produce rarefraction waves that may greatly affect the actual size of the breach. The effect of the water reservoir on the crater produced in a dam structure by detonation of a weapon emplaced within, on the side of, or at the base of the dam may be even more significant. Although considerable research had been done in regard to water-shock effects on a dam, the quantitative influence of the water medium on an explosion at the water-rock interface (tamping effect) remains uncertain. Furthermore, the extrapolation of existing data on the dimensions of the craters and rupture zones created by full-scale explosions in dry environments to cover similar

explosions in an underwater environment would be of questionable validity, at best.

Finally, if a minimum-yield weapon is used for demolition, the postshot structural stability of the target may become very significant. In the case of a bridge or a dam, for instance, the weapon yield may be far less than that required to create complete destruction by the explosion itself, yet the installation may be so weakened that the dead load conditions existing after the explosion are sufficient to make failure probable, if not certain.

It seems apparent that these gaps in the present state of knowledge concerning low-yield nuclear weapons effects on submerged or semisubmerged hard structures must be at least partially filled before low-yield nuclear weapons can be confidently employed on targets of this nature.

3.2 ANALYSIS OF MODELING TECHNIQUES

One of the most frequently used methods of analyzing the effects of large explosions, including low-yield nuclear weapons effects, is the technique of small-scale modeling. The majority of References 14 through 24, reviewed in Chapter 2, involve the simulation of such explosions under various conditions by modeling. Although many of these references were not originally intended to apply directly to the effects of low-yield nuclear weapons on

submerged or semisubmerged hard targets, much of the data as well as the modeling techniques employed may be of significant value in analyzing such effects, both directly and by further model testing. Accordingly, a review of model scaling techniques, as applied to explosion modeling, is included in the succeeding paragraphs.

Fundamental to any consideration of modeling of explosion effects is an identification of the primary factors involved. This has been attempted in a number of investigations on this subject (References 30 through 35), with considerable variance in the conclusions reached. Tentatively, the function

$$V = f(Y, C_s, \epsilon_\rho, V_d, \theta_c, \rho_m, w_c, E_m, \eta_m, \mu, \theta_m, Z, \upsilon, p, g) \qquad (3.1)$$

is believed to contain all the factors that exert significant influence on the cratering process. The terms in Equation 3.1 are defined as follows.

V = the crater (apparent or true) volume, with a dimension of L^3 in the mass-length-time (MLT) system of dimensions

Y = energy yield of the explosive, ML^2T^{-2}

C_s = a charge shape factor, applicable to chemical or high explosives only, and dimensionless

ϵ_ρ = energy density of the explosive charge, $ML^{-1}T^{-2}$

V_d = charge detonation velocity, LT^{-1}

θ_c = thermal output of the charge. Although the differences in thermal properties of HE and NE have long been recognized, no analyses available to the authors identify these properties in relation to their importance in cratering. The dimensions of this term are, therefore, intentionally omitted.

ρ_m = density of the cratered medium, ML^{-3}

w_c = moisture content of the medium, dimensionless

E_m = elastic properties of the medium, or yield strengths, $ML^{-1}T^{-2}$

η_m = void ratio of the medium, dimensionless

μ = Poisson's ratio for the cratered medium, dimensionless

θ_m = thermal response of the medium, perhaps in terms of vaporizing or melting points

Z = charge depth of burial, L

υ = dynamic viscosity of the medium, $ML^{-1}T^{-1}$

p = hydrostatic pressure exerted on the cratered medium, $ML^{-1}T^{-2}$

g = gravitational constant of acceleration, LT^{-2}

Volume is chosen as the dependent variable in the above expression, since it may more consistently represent the energy expended in crater formation. Using the crater volume and an appropriate "shape" factor (Reference 36), other crater dimensions can be readily

obtained. For purposes of a dimensional analysis, Equation 3.1 can immediately be simplified by excluding the singularly composed dimensionless terms since they will not affect scaling relations. Further, experimental conditions may at times render some of the above terms insignificant.

The ambiguity of the above expression (Equation 3.1) is recognized; however, until the insignificant terms are positively identified as having very little effect on the overall cratering phenomena, all terms must be considered. The primary purpose here is to demonstrate the many ramifications of the cratering problem, which has defied a general solution in spite of a concentrated research effort throughout the past decade or so.

Assuming that a reasonable selection of physical quantities has been accomplished, the next step in explosion effects modeling is to choose the scaling exponent which is applicable (a single scaling law may suffice for crater dimensions, but other effects may scale differently). A very thorough examination of theoretical and empirical scaling laws (Reference 33) indicates that (1) there is still insufficient experimental evidence to conclusively demonstrate the superiority of any single scaling law, (2) fourth-root <u>energy</u> scaling (as opposed to the use of charge weight in terms of TNT or its equivalent weight) appears to most nearly satisfy the theoretical aspects of explosion scaling, but introduces stringent

similarity requirements in several factors which the experimenter usually cannot control, and (3) an approximate scaling method known as "overburden" scaling (taking into account the combined earth overburden and atmospheric pressure on the cratered medium) may be best from a practical viewpoint, spanning the gap between the classical cube-root scaling, adequate for small explosions, and the more "theoretically correct" fourth-root law.

Due to the scarcity of data available on these burst geometries, the validity of these latter two conclusions as they affect surface or near-surface detonations is yet to be shown. Limited observations (Reference 28) hint at possible deviations. Further, the basic differences in chemical and nuclear explosions are almost surely manifested in the mechanisms of cratering (Reference 37) and thereby in the crater sizes and shapes formed by such explosions. In the absence of further experimentation, however, the conclusions of Reference 33 seem to offer the best scaling guide available.

It remains at this point to consider that a <u>structure</u> is under consideration and that the explosions will occur in close proximity to boundaries, rather than in the infinite half-spaces usually assumed in crater research (Section 3.1.3). This is perhaps the most severe limitation to a theoretical approach since so little is known about dynamic structural response to such high levels of stress. Although at least one excellent treatment of the general problem of modeling

structures is available (Reference 38), it must be considered a guide only; many of the responses under investigation in this experiment will be beyond the proportional (elastic) limits of the materials, and reflections and rarefractions of shock waves can be expected to complicate the analysis.

In summary, the development of a realistic or true modeling system seems practically impossible. There are numerous examples of adequate models of this type, however, which, within rather restricted limits, provide reasonably accurate results. Most of the documented experience with such modeling is in an earth medium, and preparation of an adequate structural model for cratering phenomena is of questionable practicality largely because of the necessity for scaling lithostatic (gravity) stresses and the limitations imposed by the several scaling laws. The reasoning behind this discussion led to the formulation, of the indirect modeling approach described in Chapter 4.

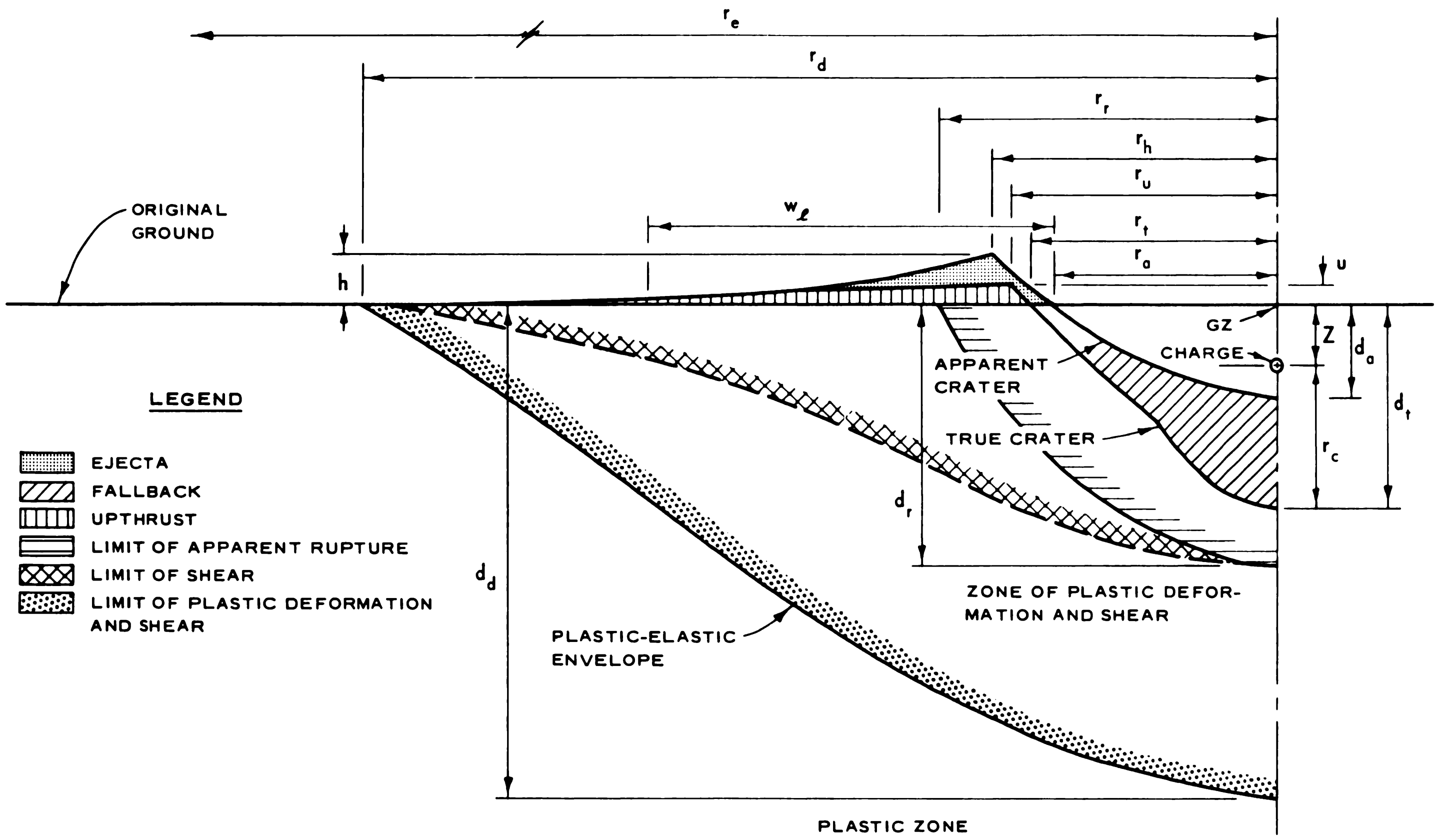
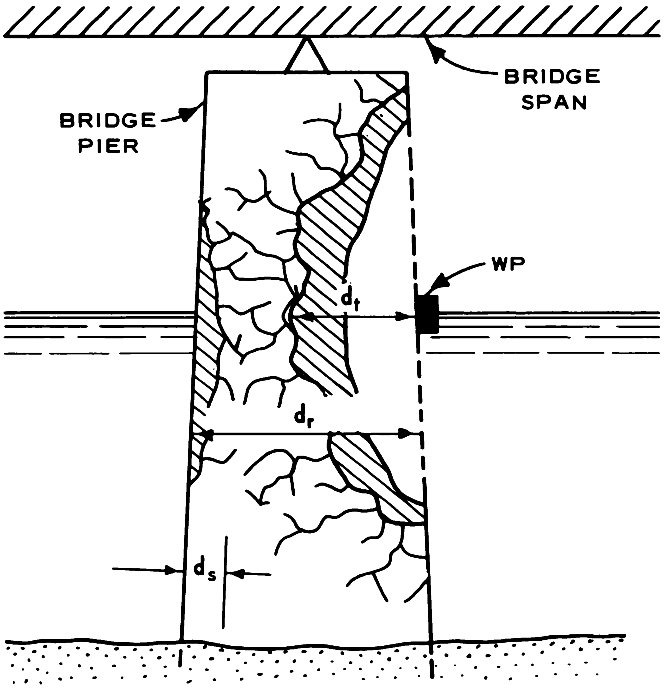


Figure 3.1 Typical half-crater profile and notation. Profiles and dimensions are symmetrical about the centerline.



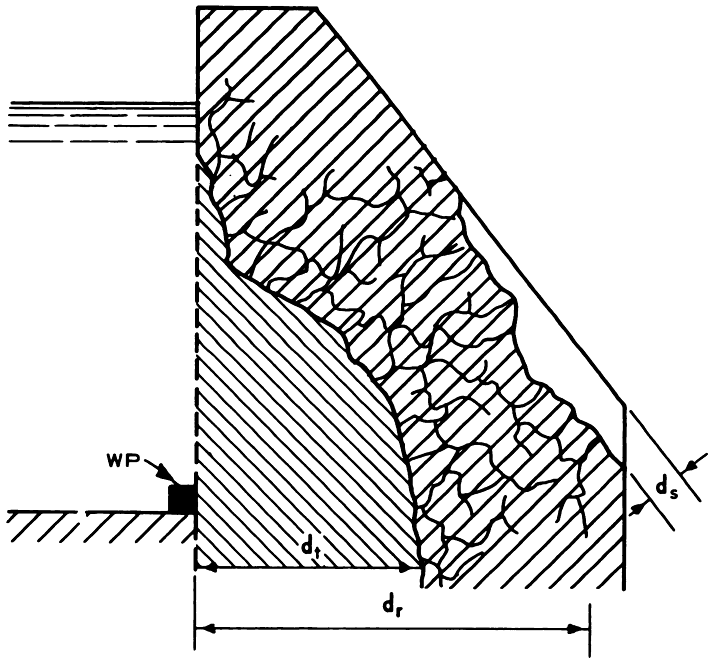
d_t = TRUE CRATER DEPTH

d_r = DEPTH OF RUPTURE

d_s = DEPTH OF FREE SURFACE SPALL

WP = WEAPON PLACEMENT (POINT OF DETONATION)

Figure 3.2 Contributions of rupture and spall to effects of demolition of a bridge pier by low-yield nuclear weapons.



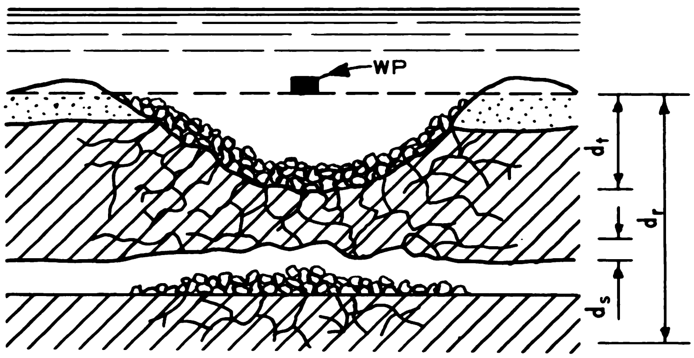
d_t = TRUE CRATER DEPTH

d_r = DEPTH OF RUPTURE

d_s = DEPTH OF FREE SURFACE SPALL

WP = WEAPON PLACEMENT (POINT OF DETONATION)

Figure 3.3 Contributions of rupture and spall to effects of demolition of a gravity dam by low-yield nuclear weapons.



d_t = TRUE CRATER DEPTH

d_r = DEPTH OF RUPTURE

d_s = DEPTH OF FREE SURFACE SPALL

WP = WEAPON PLACEMENT (POINT OF DETONATION)

Figure 3.4 Contributions of rupture and spall to effects of demolition of an underwater tunnel by low-yield nuclear weapons.

CHAPTER 4

PROPOSED PROGRAM OF INVESTIGATION

4.1 OBJECTIVE

The objective is to determine the effects of explosions on submerged and semisubmerged hard targets, with emphasis on the influence of the unique geometeries and environmental conditions involved on the results of contact or near-contact explosions. An indirect modeling approach, described in the following section, will be used to extrapolate the effects observed at small scale to infer the damage potential of much larger explosions (either conventional or nuclear).

4.2 APPROACH

The proposed program consists of four phases. The first phase entails the development of new and/or improved cratering curves for large-scale explosions, both nuclear and conventional, and the development of a corresponding curve for small-scale cratering explosions, based on a series of experimental tests. The small-scale curves will be used for qualitative correlations only.

Reliable cratering curves for realistic NE and HE charge yields are essential for the development of a refined technique for the prediction of the effects of nuclear weapons employed in the manner stated above. Much new data from full-scale tests, some as late as 1965, and recent advances in analytical investigation methods for

nuclear weapons effects make it necessary to reconsider the existing crater prediction guides. In addition, crater scaling procedures for nuclear explosions at the surface of a hard medium are needed in order to meaningfully relate model and full-scale results. At present, only one nuclear detonation involving a low-yield device at the surface of a hard medium has occurred. More information is needed before cratering effects can be confidently predicted for surface nuclear weapons.

The curves for small-scale cratering explosions will be developed by firing a series of small charges (from a few grams to about 10 kg of TNT or equivalent) in an infinite half-space of strength-controlled cement grout. These curves will be used as a basis for a qualitative extrapolation of the effects of small-scale explosions under nonideal conditions (that is, with nearby boundaries or reflecting surfaces, as in a structure) to the predicted effects of large-scale explosions occurring under similar nonideal conditions.

The second phase of this program involves tests of small-scale charges on structures representative of submerged and semi-submerged hard targets. These tests will be divided into three series, and will be designed to generally reproduce the differences (1) in the geometry of the targets, (2) in the environmental conditions of the targets, and (3) in the burst positions of nuclear weapons employed on these targets. The primary types of structures

to be modeled will be various types of dams, bridge piers and abutments, and underwater tunnels.

In the third phase of the small-scale test program, the test results of Phase II will be interpreted and applied to specific examples of submerged and semisubmerged hard structures which are likely targets for demolition by nuclear weapons.

Finally, a fourth phase is tentatively planned in which large-scale structures, similar to the models used in Phase II, will be tested using large-scale HE charges. The purpose of this phase will be to confirm and validate the results obtained in the small-scale testing program and insure a reliable extrapolation of these results to the effects of full-scale demolition of practical targets.

4.3 PROCEDURE

4.3.1 Phase I: Cratering Effects Under Idealized Conditions. To develop a cratering curve for large-scale explosions, all available data on cratering results from full-scale tests (both NE and HE) which might apply to this study will be reviewed to formulate new or improved curves for nuclear explosions, particularly in the small-yield range. Emphasis will be placed on surface detonations in rock media.

To develop a basic cratering curve for small-scale explosions, a series of spherical TNT (or eqivalent) charges will be fired on

the surfaces of slabs constructed of strength-controlled grout (Figure 4.1). The grout mixture will be carefully controlled to insure consistency in the properties of the medium to be cratered. The slabs will be of sufficient size so that the opposing external surfaces will have a minimum effect on the crater formations. The range of yields for the charges is anticipated to be from about 25 grams to about 10 kg. Charges will be fired on both horizontal and vertical surfaces. These shots will be fired at both air-grout and water-grout interfaces, with emphasis on the study of cratering mechanisms in the latter case. The half-space testing will include crater-penetration experiments against model tunnels beneath a surface shot in grout. This will include various tunnel configurations and charges fired both in dry grout and with water overburden (Figure 4.2). Special emphasis will be placed on the submerged condition, with variations in water depth and with the addition of a fine-grained overburden on the grout, such as would be expected to overlie a bedrock formation beneath a body of water.

4.3.2 Phase II: Cratering Effects Under Nonideal Conditions. In the first series of tests, special test structures will be constructed of cement grout of composition identical with that used in Phase I. These structures, however, will have geometric configurations which approximate in cross section the basic shapes generally found in dams, bridge piers, below-bottom tunnels, and similar

structures. Small, spherical TNT charges will be fired on the tops and sides of these test structures to determine the effect on crater size and shape of adjacent surfaces which will act as sources of shock reflection (Figure 4.3). The range of charge yields fired will be limited, probably to two or three intermediate yields; however, a sufficient number of tests will be fired under each individual test condition to assure reliability of results.

In the second series, test structures with a rectangular cross section will be constructed and emplaced in a basin with water against one or both sides of the structure, generally approximating the environmental conditions for dams, bridge piers, and similar structures. Test charges will be fired on one or both sides of these structures, with the height of burst on the structure surface varied from the water level to the base (Figure 4.4).

In the third series, special test structures will be constructed of cement grout with model tunnels or galleries in the center of each structure, parallel to the longitudinal axis. Untamped charges will be fired within the tunnels of these structures to simulate partially contained explosions emplaced within dams, both arch and gravity types. A limited range of charge weights will be used, and the test structures will vary only in width-to-height ratios (Figure 4.5).

<u>4.3.3 Phase III: Interpretation of Results of Small-Scale Tests</u>. In particular, the effects of the test variables in each

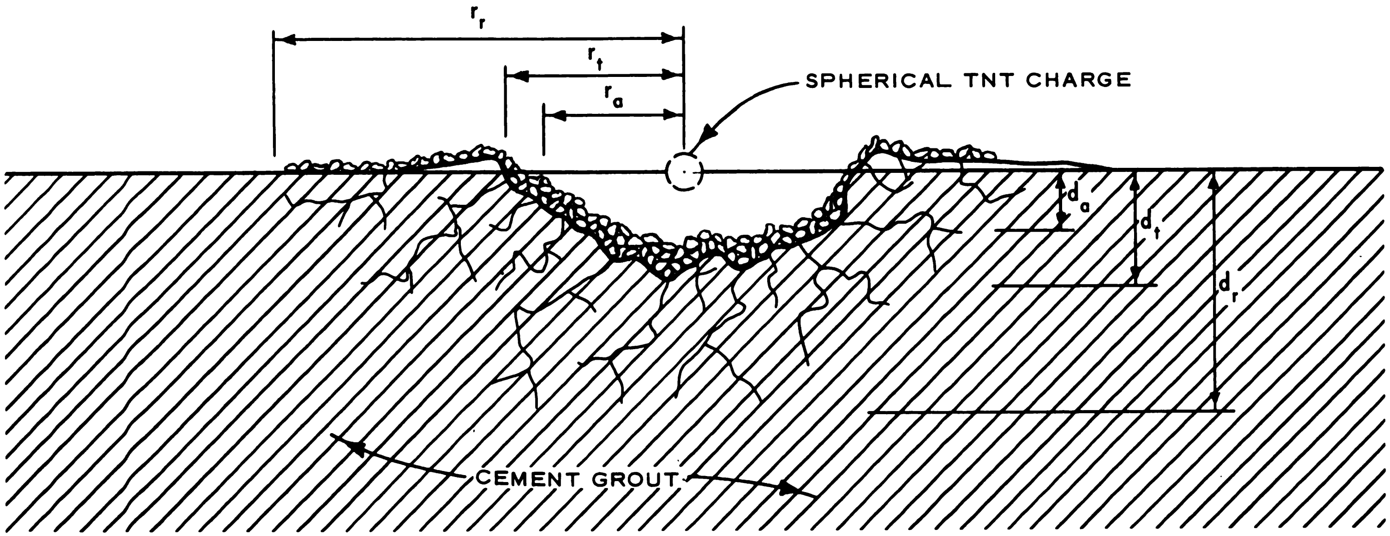
series on the crater size and shape and the depth and radius of the true crater and rupture zone will be analyzed. The effects of the test variables in one series will also be applied to the conditions represented in other series, so that the results may be extrapolated to cover any variation in the structure configuration and/or environment. In addition, the condition of each structure after testing will be examined to evaluate the degree of destruction inflicted and the probable usefulness of the structure, and to determine, if applicable, what would be required to cause complete destruction of the structure. The postshot structural integrity of the structures will be investigated by selecting representative models from each of the Phase II tests and subjecting them to static loadings in a manner designed to simulate the natural loading conditions of the prototype structure. The relative decrease in load-supporting ability will thus be determined by comparing the loadings necessary to cause failure in the preshot and postshot model samples. Also in this phase of the program, the variables involved in relating model to full-scale test results will be considered and compared by means of dimensional analysis and the theory of similitude (Reference 38).

Finally, the results and conclusions derived from the test results of Phase II will be applied to the basic cratering data for full-scale nuclear detonations (from Phase I) to establish a prediction system for the effects of low-yield nuclear weapons employed

against submerged and semisubmerged hard targets. This will be accomplished primarily by a qualitative comparison of the results achieved in the small-scale test configurations with the best available full-scale cratering curves, rather than by direct extrapolation through several orders of magnitude. Thus, the effects of low-yield nuclear weapons on dams, bridges, and tunnels will be inferred by (1) noting changes in small-scale craters caused by differing geometries and environments, (2) determining in the models which crater parameters govern the destruction of various structural sections, and (3) applying these observations to the full-scale cases for typical submerged and semisubmerged hard structures.

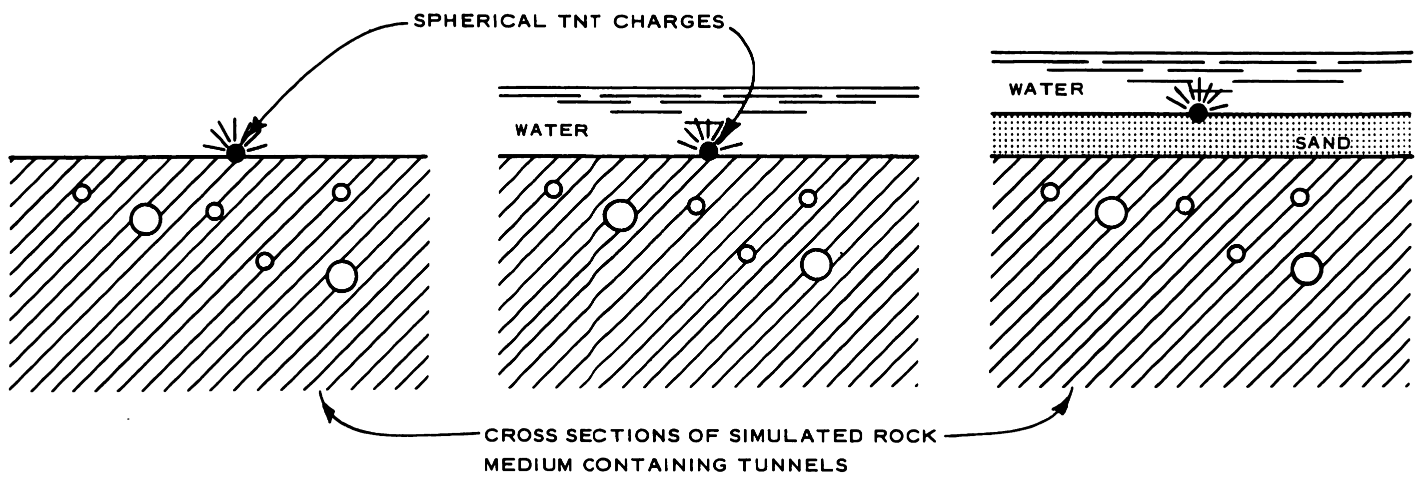
4.3.4 Phase IV: Large-Scale Tests. Upon conclusion of the small-scale testing program outlined above, it is anticipated that a large-scale testing program will be initiated using full-scale test structures which have outlived their usefulness. It seems apparent, even at this early stage, that such testing will be extremely valuable in confirming and validating the empirical results and conclusions obtained in the small-scale program, so that practical use can be made of these results and conclusions. Since the specific requirements for this program will be largely based on the results of the small-scale test program, it would be premature to set forth a detailed experimental plan at this time. One of the major possibilities under consideration, however, is the aquisition of

permission to conduct demolition experiments on obsolete hydraulic structures scheduled for destruction in the course of new civil works projects. The use of such structures for test purposes is not without precedent (Reference 22), and it is hoped that the cooperation of various government agencies, such as the Army Corps of Engineers, the Bureau of Reclamation, etc., in locating these structures will make such a program feasible and will result in considerable savings by avoiding the necessity of constructing large-scale structures solely for testing purposes. A more definitive proposal for this anticipated program will be presented in a later report of this series.



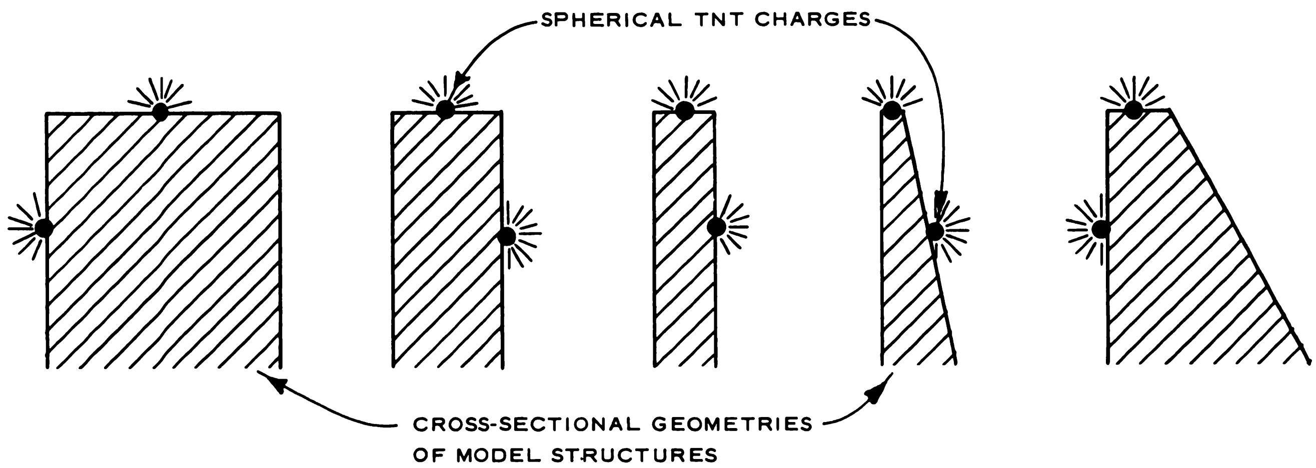
TEST PARAMETERS		TEST OBJECTIVES	RESULTS TO BE MEASURED
CONSTANTS: SHOT GEOMETRY MEDIUM (GROUT PROPERTIES)	VARIABLES: CHARGE WEIGHT	TO ESTABLISH A CRATERING CURVE FOR SMALL-SCALE DETONATIONS AT SURFACE OF A SEMI-INFINITE TEST MEDIUM.	CRATER AND RUPTURE ZONE DIMENSIONS (SEE FIGURE 3.1 FOR NOTATION).

Figure 4.1 Illustration of cratering test plan for Phase I of proposed small-scale testing program.



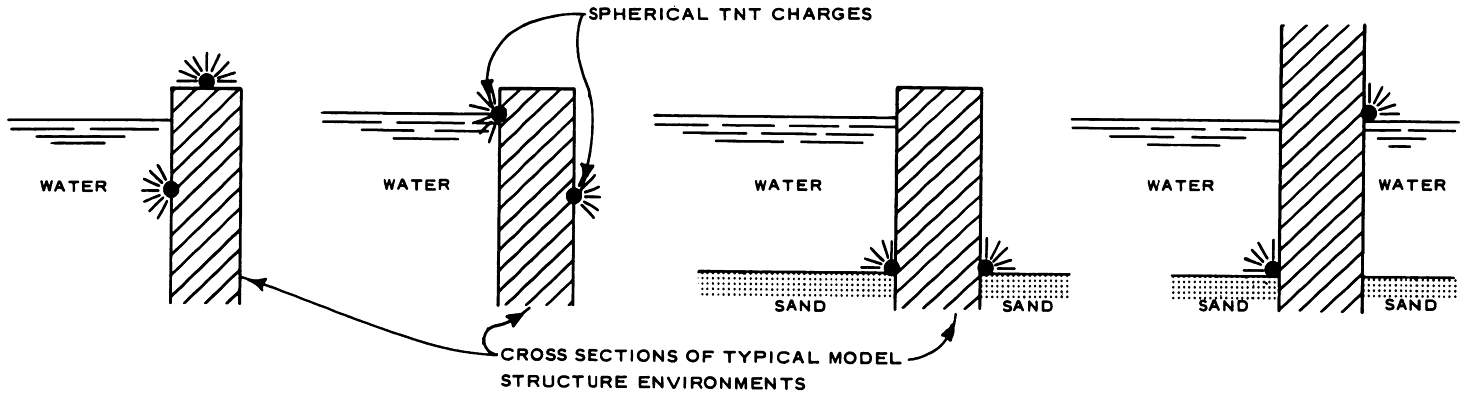
TEST PARAMETERS		TEST OBJECTIVES	RESULTS TO BE MEASURED
CONSTANTS: MEDIUM (GROUT PROPERTIES), CHARGE WEIGHT, MODEL GEOMETRY	VARIABLES: CHARGE LOCATION, SHOT ENVIRONMENT	TO DETERMINE THE TAMPING EFFECT OF A WATER MEDIUM ON CRATERING AND TUNNEL-DESTRUCTION EFFICIENCY OF CHARGES FIRED ON A SOIL- (ROCK-) WATER INTERFACE.	CRATER AND RUPTURE ZONE DIMENSIONS; DEGREE OF TUNNEL DESTRUCTION

Figure 4.2 Illustration of tunnel-penetration test plan for Phase I of proposed small-scale testing program.



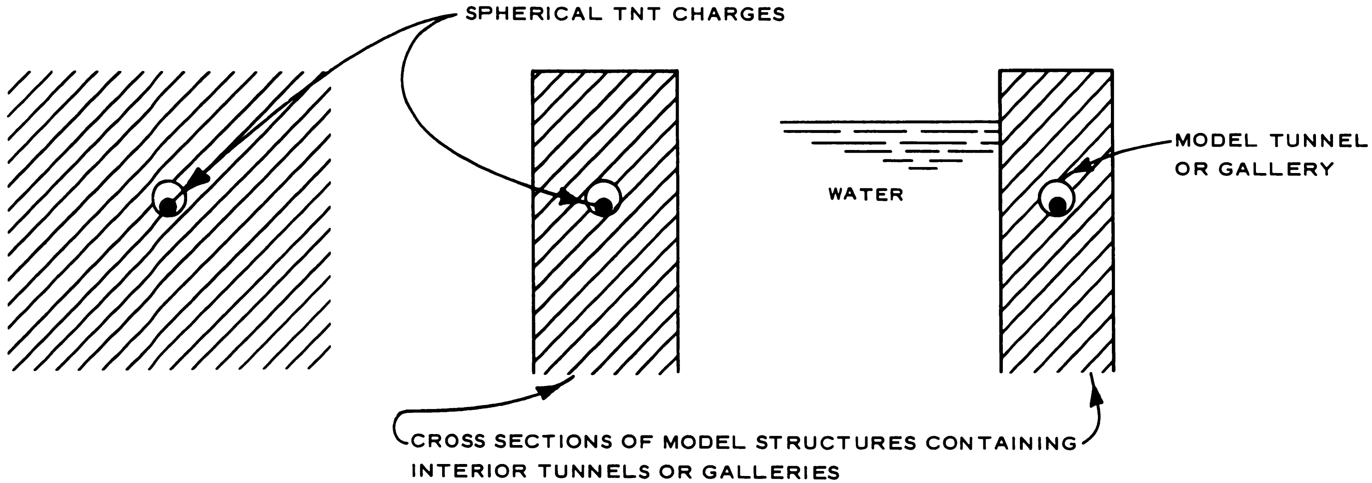
TEST PARAMETERS		TEST OBJECTIVES	RESULTS TO BE MEASURED
<u>CONSTANTS:</u>	<u>VARIABLES:</u>	TO DETERMINE THE EFFECT OF MODEL STRUCTURE GEOMETRY ON CRATERING EFFICIENCY.	CRATER AND RUPTURE ZONE DIMENSIONS (INCLUDING SPALL CRATER)
MEDIUM (GROUT PROPERTIES)	CHARGE WEIGHT		DEGREE OF DESTRUCTION
CHARGE DEPTH	CHARGE LOCATIONS		POSTSHOT STRUCTURAL INTEGRITY
	MODEL GEOMETRIES		

Figure 4.3 Illustration of test plan for Phase II, Series 1 of proposed small-scale testing program.



TEST PARAMETERS		TEST OBJECTIVES	RESULTS TO BE MEASURED
CONSTANTS:	VARIABLES:	TO DETERMINE THE EFFECT OF MODEL STRUCTURE ENVIRONMENT ON CRATERING EFFICIENCY.	CRATER AND RUPTURE ZONE DIMENSIONS (INCLUDING SPALL CRATER)
MEDIUM (GROUT PROPERTIES)	CHARGE WEIGHT		DEGREE OF DESTRUCTION
CHARGE DEPTH	CHARGE LOCATION		POSTSHOT STRUCTURAL INTEGRITY
MODEL GEOMETRY	SHOT ENVIRONMENT		

Figure 4.4 Illustration of test plan for Phase II, Series 2 of proposed small-scale testing program.



TEST PARAMETERS		TEST OBJECTIVES	RESULTS TO BE MEASURED
CONSTANTS: MEDIUM (GROUT PROPERTIES) CHARGE LOCATION	VARIABLES: CHARGE WEIGHT MODEL GEOMETRY SHOT ENVIRONMENT	TO DETERMINE THE EFFECT OF PARTIAL CONTAINMENT OF CHARGES ON CRATERING EFFICIENCY.	CRATER (CAVITY) AND RUPTURE ZONE DIMENSIONS (INCLUDING SPALL CRATERS) DEGREE OF DESTRUCTION POSTSHOT STRUCTURAL INTEGRITY

Figure 4.5 Illustration of test plan for Phase II, Series 3 of proposed small-scale testing program.

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13. ABSTRACT

This report presents a state-of-the-art examination of the effects of low-yield nuclear weapons, including atomic demolition munitions, on submerged and semisubmerged hard targets. Twenty-five references dealing with low-yield nuclear weapons employment, effects, or related subjects are reviewed, and the collective information represented by these references is discussed. Areas in which sufficient knowledge is lacking are defined. On this basis, a program of investigation and testing with small- and large-scale conventional charges and structures is proposed.

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